Asbestos remains a serious and controversial occupational and environmental hazard worldwide, and asbestos-related disease claims continue to be the leading “toxic tort” issue, especially in the United States. Despite public pressure to ban the production and use of all asbestos fiber types, they are still being mined and used in China, the former Soviet Union, Mexico, and other countries.

In the last two decades, landmark works in the field of asbestos risk assessment and quantification have incorporated epidemiological data from seven countries. Though public health agencies worldwide have not yet agreed on a universal methodology, effective asbestos risk assessment approaches need to be addressed with different asbestos fiber types in mind.
The Basics

According to OSHA, asbestos “includes the mineral fibers chrysotile, amosite, crocidolite, tremolite, anthophyllite, actinolite, and any of these minerals that have been chemically treated or altered.” There is no doubt that all types and forms of asbestos are dangerous. Microscopic asbestos fibers can penetrate the human respiratory tract and interact directly or indirectly with cell chemistry, including DNA, sometimes causing cancer. However, not all asbestos fibers are the same, and their relative toxicity or potency with respect to human health risk varies.

Asbestos can be divided into two distinct asbestos-form mineral groups: serpentine asbestos and amphibole asbestos. Serpentine asbestos fibers (chrysotile) are low in iron concentration. They have distinct fiber morphology and magnesium hydroxyl groups on the surface, which allow decomposition in acidic environments or with certain enzymes. With a half-life of weeks in the lung, serpentine fibers are relatively easily cleared by the human body. In contrast, amphibole asbestos fibers (like amosite and crocidolite) are higher in iron, more chemically resistant, and more difficult for the human body to clear, with half-lives of decades in the lung.

Other important factors that determine the adverse health effects of asbestos are the size and shape of the fibers. Strong evidence exists that long and thin fibers are more carcinogenic than short and thick fibers.

History

In the U.S., chrysotile asbestos has been used since the late 1800s in many products, including pipe insulation and roofing materials. Amphibole asbestos was not frequently used until the World War II era. In the 1950s, the popular press classified asbestos as the “miracle mineral” because of its multiple uses and life-saving properties as a fire retardant and insulator.

The 20th century became an “asbestos epoch” for many countries. In the U.K., unique “blue asbestos,” or crocidolite, was extensively used in the maritime industry. Amphibole forms of asbestos were introduced because of their light weight, resistance to attack by saline solutions, and resistance to high temperatures. After World War II, Germany utilized spray-applied fireproofing containing crocidolite in areas that needed large-scale post-bellum reconstruction. Australia and South Africa were major exporters of asbestos, and some of the first epidemiological studies regarding the risks of mortality associated with asbestos exposures originated in these countries.

Chrysotile asbestos has been mined and milled in many locations throughout the world. For decades Canada was the world’s leading producer of chrysotile, but was subsequently surpassed by Russia.

By the 1960s, asbestos insulators in the U.S. appeared to have a significant excess of asbestosis, lung cancer, and mesothelioma, and ACGIH began the long process of lowering the time-weighted average (TWA) Threshold Limit Value (TLV). The initial standard of 5 mppcf, which equates to approximately 30 fibers per cubic centimeter (f/cc), progressively decreased to today’s limit of 0.1 f/cc. The current TLV is used in many countries.

OSHA set its TWA permissible exposure limit (PEL) to 12 f/cc in 1971 and gradually reduced it to today’s level of 0.1 f/cc with a peak/ceiling exposure threshold of 1 f/cc. In 1975, ACGIH promulgated fiber-type specific TWA-TLVs for asbestos: 0.2 f/cc for crocidolite, 0.5 f/cc for amosite and tremolite, and 2 f/cc for chrysotile and other mineral forms of asbestos.

Today, the use of asbestos in various products has been effectively eliminated in the U.S., yet the problems presented by asbestos exposure remain. For several reasons, the risk of developing an asbestos-related disease, particularly mesothelioma, has not been eradicated.

First, chrysotile, crocidolite, amosite, and other forms of asbestos are still present in old building materials, talc, and vermiculite. Exposures have been greatly reduced since those observed 30 years ago, but several case-control studies in France and Germany have demonstrated that a worker’s exposures to amphibole forms of asbestos, even when close to the typical cumulative lifetime background exposure level (roughly 0.1 f/cc-years), still increased the worker’s risk of disease.1–3,4

Second, asbestos is still actively produced and utilized by many countries, with more than 2 million tons of chrysotile produced annually, according to the United States Geological Survey. Some countries also continue to use amphibole forms of asbestos.

Third, asbestos is often associated with other minerals. The significant risk of mesothelioma is
becoming apparent in mining and construction-related activities, and public health agencies and private industry are increasing their efforts to study the “naturally occurring asbestos” (as if other asbestos could occur unnaturally).

For these reasons, the anticipation, recognition, evaluation, and control of asbestos hazards and risks in both occupational and community settings requires more skill and knowledge than ever before.

ASBESTOS AND THE PRECAUTIONARY PRINCIPLE
Risk assessment allows us to look into the future and provide invaluable feedback for informed decision making. The industrial hygiene community should be familiar with the concepts of hazard, risk, and safety regarding risk assessment associated with asbestos exposures. “Hazard” is the potential to do harm, “risk” is the probability that the potential harm will occur, and “safety” is the achievement of acceptable risk. While eliminating risk is impossible, the health risks of asbestos exposures can be measured and managed by quantifying the probability of a disease outcome based on exposure estimates and other factors.

Evaluating asbestos health risks begins with exposure assessment. Note that asbestos sampling and measurement techniques involve various uncertainties and random characteristics, including the determination of similar exposure groups (SEGs), the extrapolation of daily measurements versus long-term exposures, the individual variability of results as they relate to dose-response relationships, and the high variability associated with analytical methodologies.

Asbestos exposure reconstruction methodologies have advanced over time. Today, retrospective exposure and risk can be estimated based on the meta-analysis of numerous publications, confirmed by simulation studies, mathematical modeling, and pathological measurements of asbestos lung burden. Despite potential uncertainties, these methodological advances improve dose-response estimations in risk assessment models.

Unfortunately, we cannot rely entirely on animal studies to know the effects of specific asbestos exposure levels on humans because of vast differences in lifetimes, respiratory tracts, and toxicological modes of action. In addition, a pharmacokinetic model that simulates the process of asbestos toxicity has not yet been developed.

Epidemiological observations, including both cohort and case-control studies, remain important to developing asbestos risk assessment protocols. For example, in an Australian crocidolite asbestos mine, with 72 cases of mesothelioma in a cohort of 7,000 workers, an estimated average cumulative exposure of 23 f/cc-years was observed. In a Quebec chrysotile mine and mill, there were 33 cases of mesothelioma among 11,000 workers, with an average observed exposure of 600 f/cc-years. However, we must also consider the usual concomitant uncertainty of diagnosis and mortality monitoring.

Among approximately 20 worldwide cohort studies, the first asbestos dose-response models were developed and applied in the U.K. and the U.S. As part of an EPA initiative in 1986, William Nicholson published one of the most widely used regulatory models for determining asbestos health risks. In 2000, John Hodgson and Andrew Darnton introduced a revolutionary non-linear approach to estimate the dose-response relationship, which considers not only the level of exposure but also the mineral fiber type of the asbestos. In 2008, Wayne D. Berman and Kenny Crump further developed Nicholson’s ideas and demonstrated that asbestos health risk assessment should consider not only mineral fiber type, but also fiber size and dimensionality. Also in 2008, EPA updated a simplified approach of Nicholson’s ideas in its Integrated Risk Information System (IRIS) that included exposure duration and age of exposure onset. Darnton updated his calculations in 2010 based on new published studies and demonstrated that the conclusions of his previous work with Hodgson were still valid.

Applying these new models yields practical insights equal in importance to their theoretical value. One such insight is that an understanding of the discrepancies of risk estimations should inform decision making, risk management, and communication. Today’s regulatory bodies assume the current fiber potency for mesothelioma as an average from available epidemiology studies, regardless of fiber type. However, according to updated risk assessment models, a TWA exposure of 0.1 f/cc to crocidolite asbestos for 30 years, with an onset age of 25 years, would result in a lifetime risk of mesothelioma in the range of 12,000 to 21,000 cases per million, approximately 6 to 10 times higher than the current EPA model predicts. In addition, updated models suggest
that previously estimated risks associated with exposures to amphibole asbestos may be significantly underestimated, while the risks for exposure to pure chrysotile may be overestimated.

One lesson remains. Through the precautionary principle and other considerations, public health agencies currently treat serpentine and amphibole fiber risks as having equal disease potency, when in reality the risks associated with amphiboles are probably understated in the current regulatory risk assessment approach by up to an order of magnitude. As a result, the current occupational exposure limit, while likely being sufficiently protective for chrysotile, may not be sufficiently conservative in many instances for low-level amphibole asbestos exposures. In fairness, NIOSH has recommended that asbestos exposures be kept to the lowest feasible level. In addition, even based on “average” cancer potency factors between chrysotile and amphibole asbestos fibers, OSHA has stated that excess risk is present with the current 0.1 f/cc standard.

A LOOK INTO THE FUTURE
Asbestos health risk assessment approaches have been scrutinized and criticized for many years. Some have questioned how well we could predict risk based on existing epidemiological studies. Several factors introduced uncertainty into the risk models, including potential exposure assessment bias and variability, potential epidemiological biases and confounders, subtle mineralogical differences in primary fiber exposures, impurity variability of various asbestiform fiber types, and the presence of associated non-asbestiform elongated minerals.

However, the science of asbestos risk assessment has progressed significantly during the last few decades through updated risk models and innovative statistical methods to evaluate risk, as well as access to additional data sources (for example, Russian mesothelioma information).14

The results of the most reliable and recent case-control studies in Europe can be adequately described in terms of asbestos amphibole risk models, even at an exposure level one to two orders of magnitude below the cumulative asbestos exposure associated with current North American occupational exposure limits.

Much progress has been made, and asbestos exposure and risk assessment models will be further refined by improved knowledge of toxicological mechanisms, updates to epidemiological study risk ratios, and development of associated fiber-specific disease potency factors. Information from existing asbestos-exposed cohorts will be expanded and further analyzed. To truly assess risk, industrial hygienists need an in-depth understanding of the newer asbestos risk assessment models, as well as the historical approaches upon which our occupational exposure standards have been based. Moreover, the asbestos risk assessment approach is potentially useful for other applications involving man-made fibers, nanoparticles, and many other dangerous substances.

Asbestos represents a significant international problem. The science of risk assessment can help promote a clear vision for society to manage asbestos risks effectively.

2. “Asbestos and Man-Made Vitreous Fibers as Risk Factors for Diffuse Malignant Mesothelioma: Results from a German Hospital-Based Case-Control Study,” American Journal of Industrial Medicine, March 2001.